

UAVSAR Instrument: Current Operations and Planned Upgrades

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Abstract - The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) instrument is a pod-based L-band polarimetric synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. This instrument is currently installed on the NASA Gulfstream-III (G-III) aircraft with precision real-time Global Positioning System (GPS) and a sensor-controlled flight management system for precision repeat-pass data acquisitions. UAVSAR has conducted engineering and preliminary science data flights since October 2007 on the G-III. We are porting the radar to the Global Hawk Unmanned Airborne Vehicle (UAV) to enable long duration/long range data campaigns. We plan to install two radar pods (each with its own active array antenna) under the wings of the Global Hawk to enable the generation of precision topographic maps and single pass polarimetric-interferometry (SPI) providing vertical structure of ice and vegetation. Global Hawk's range of ~8000 nm will enable regional surveys with far fewer sorties as well as measurements of remote locations without the need for long and complicated deployments. We are also developing P-band polarimetry and Ka-band single-pass interferometry capabilities on UAVSAR by replacing the radar antenna and front-end electronics to operate at these frequencies.

I. INTRODUCTION

The Uninhabited Airborne Vehicle Synthetic Aperture Radar (UAVSAR) is a compact, reconfigurable, pod-based imaging radar instrument developed under NASA Earth Science Technology Office funding beginning in 2004. The L-band fully polarimetric SAR (POLSAR) with repeat-pass interferometric (RPI) observation capability currently flies underneath NASA's Gulfstream-III jet to provide measurements for science investigations in solid earth and cryospheric studies, vegetation mapping and land use classification, archaeological research, soil moisture mapping, geology and cold land processes [1,2,3]. Since commencing operational science observations in January 2009, we have flown over 150 flights acquiring 1700 flight lines of data in 12

countries. We have delivered over 15 TB of POLSAR and RPI data products to the science investigators.

UAVSAR's modular and reconfigurable design enables us to utilize the instrument as a flying test-bed for the development of future space missions. Two identical L-band radar systems (pods) were built and flight-tested. We are modifying the system to utilize two pods on the long-range high endurance Global Hawk UAV for single-pass interferometric observations to map surface topography and study vegetation structure. The porting of the radar to the Global Hawk UAV will enable long duration/long range data campaigns. The Global Hawk endurance of nearly a day will enable long loiter time over dynamic targets such as volcanoes and earthquake-prone regions for pre-event signature studies or post-event scientific and hazard management activities. The Global Hawk range on the order of 8000 nm will enable data collection of distant areas of interest such as Greenland and Antarctica without complicated campaign deployments. In addition, the two radar pods, each equipped with an active array antenna, will enable high precision topographic map generation and single pass polarimetric-interferometry (SPI) for vegetation structure measurements. Global Hawk is an ideal platform for performing mapping and regional science using the UAVSAR instrument.

We have recently received funding from NASA Earth Venture-1's AirMOSS project (PI: Mahta Moghaddam) to add P-band polarimetry capability to UAVSAR to study subcanopy and subsurface soil moisture over a 3-year period. The plan is to replace the L-band active array antenna and frequency up/down-conversion electronics with a P-band passive antenna, high power amplifier, and corresponding frequency up/down-conversion electronics. In addition, the two-year NASA AITT project GLISTEN-A (PI: Delwyn Moller) is developing and integrating the Ka-band VV-polarization single-pass interferometry capability to UAVSAR. This involves the development of Ka-band front-end electronics to be mounted to the backplane of a newly developed Ka-band antenna. We plan to conduct flight tests of both the P-band and the Ka-band radars in spring 2012.

II. INSTRUMENT OPERATIONS

UAVSAR currently operates onboard the NASA/Dryden G-III aircraft based at Dryden's Palmdale Aircraft Operations Facility. The radar is remotely-controlled by a radar operator, who currently flies with the aircraft. The operator typically runs the radar in automatic mode, where the flight software executes a flight plan, which contains the waypoints and radar operational parameters for each flight line. Alternately, the radar operator can run the radar in manual mode in the event of an unplanned flight line or the need to recover from an instrument anomaly.

This year we plan to acquire 500 flight hours of L-band science and engineering data in about 90 flights where 90% of the flights are science observations and 10% of the flights are for engineering checkout of the radar or aircraft, instrument calibration, and technology demonstration such as the onboard processor. Over 80% of the science flights are repeat-pass interferometric observations of earthquake faults, volcanoes, ground subsidence, levee stability, and vegetation structure. The remaining science flights are to develop and validate soil moisture retrieval algorithms, monitor coastal wetlands, detect coastal eddies in real time, and support disaster response such as the Mexico Gulf Coast oil spill.

One of our major efforts is the semi-annual observation of the San Andreas Fault from the San Francisco Bay area down to the Mexican border to monitor deformation due to the various fault movements. An example of the deformation signature is shown in Figure 1, where the creeping of the San Andreas Fault near Monterey Bay is clearly seen in the interferogram mosaick of the data collect over a 1-year interval.

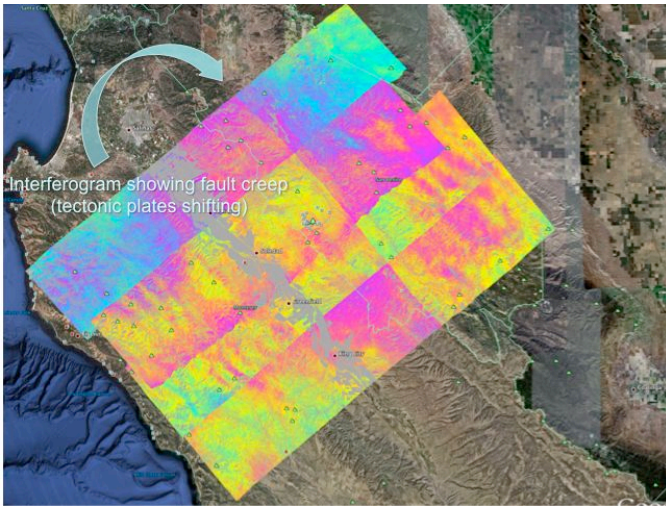


Figure 1. Interferogram of data acquired over a one-year interval (Oct. 2009- Oct. 2010) showing the creeping of the San Andreas Fault (discontinuity in phase measurements).

III. INSTRUMENT CHARACTERISTICS

Table 1 lists key radar operational parameters for UAVSAR onboard the Global Hawk (GH). The two radar antennas have a physical separation of 2.8 m, resulting in an effective antenna baseline of 5.6 m because we alternate the transmitting antennas (ping-pong mode). Although the GH is capable of flying at higher altitudes, the present NASA GH configuration is able to maintain constant altitude at altitudes less than or equal to 13.7 km (45,000 ft). This is slightly higher than the typical G-III cruising altitude of 12.5 km (41,000 ft). The GH will be flying at ~ 180 m/s, 15% slower than the typical cruising speed of the G-III (~ 215 m/s). The GH's long flight duration of 22 hours will allow us to achieve a nominal flight range of 14,500 km (7800 nm), in comparison to the G-III's nominal flight range of $\sim 6,300$ km (3400 nm).

Table 1. Key radar operational parameters for UAVSAR implementation on the Global Hawk platform.

Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Polarization	Full Quad-Polarization
Resolution	1.67 m Range, 0.8 m Azimuth
Range Swath	22 km (13.2 miles)
Look Angle	25° - 65°
Antenna Baseline	5.6 m
Platform	Global Hawk
Nominal Altitude	13.7 km (45,000 ft)
Nominal Ground Speed	180 m/s (330 knots)
Nominal Flight Duration	22 hours
Nominal Flight Range	14,500 km (7800 nm)

We expect that the relative height accuracy of the digital elevation model (DEM) generated by SPI to be on the order of a few meters depending on the terrain variation.

IV. GLOBAL HAWK IMPLEMENTATION

Implementation of single pass polarimetric-interferometry with UAVSAR instrument onboard the Global Hawk platform encompasses interfacing the two existing UAVSAR pods to the Global Hawk airframe, modifying radar control and timing to synchronize the two radar pods, ground and flight testing, and modifying the UAVSAR ground processor to generate polarimetric-interferometric data products.

Figure 2 is an artist's rendering of the UAVSAR pods under the Global Hawk wings. The two pods will be mounted symmetrically on the existing hard points under the wings. One of the radar pods will be the master pod, which consists of the complete radar. The other pod will be a slave pod where it contains an active array antenna and the motion

measurement subsystem (the inertial navigation unit and the Global Positioning Satellite antenna) to track the precise location and attitude of the slave radar antenna. The master pod will provide power, radar timing, transmit chirp, and frequency up/down-conversion for the slave pod. The digitized raw radar data will be routed to the data recorder, which will reside in the fuselage of the GH. An onboard processor is also planned to be located in the fuselage.



Figure 2. Artist's rendering of the UAVSAR pods under the Global Hawk wings

The technical effort involved in radar modification includes: 1) development of radar control software to remotely operate the radar and monitor instrument status via the Iridium satellite modem link; 2) addition of two receive channels to the master pod to receive data from the slave antenna; 3) modification of radar control and timing to command two antennas and 4 receive channels; 4) development of cable harnesses between the two radar pods and between the master pod and the fuselage equipment; 5) modification of the ground data processor to handle polarimetric-interferometric data; 6) Ground and flight testing and instrument calibration. JPL is responsible for all radar modification tasks.

The technical effort involved in aircraft modification includes: 1) design, fabrication, and installation of the wing mounting hardware; 2) redesign of the pod nose cone and tail cone if necessary to reduce flutter; 3) aerodynamic, flutter, and flight control system assessments; 4) ground vibration tests and weight and balance of the aircraft with and without the pods attached; 5) flight approval process, and 5) preparation and conduct of the flight tests within the Edwards Air Force Base range. NASA Dryden and Northrop Grumman are responsible for all aircraft modification and accommodation efforts.

V. DEVELOPMENT STATUS

We began working with Dryden and Northrop Grumman on implementing the SPI capability on the Global Hawk in early 2010. The radar modification effort is nearly completed. We have tested all functions of dual-antenna operation in the laboratory. We are currently working to increase the data recorder throughput rate. The aircraft modification effort has encountered some setbacks. After detailed aerodynamic, flutter, and flight control system assessments, Dryden aerodynamic experts concluded that the current implementation approach with existing G-III pods and radar electronics poses 3 problems:

1. Lack of ground clearance in the event of landing gear failures
2. Lack of sufficient flutter margin
3. Aerodynamic instability

The potential mitigations to these problems involve flying at lower altitudes and carrying significantly less fuel, hence reducing the flight endurance. In order to meet the required flight profile of 45,000 feet and 330 knots and flight endurance of 22 hours, we need to reduce the weight of each pod by at least 200 pounds and the pod diameter by at least 4" to overcome all 3 problems.

We can reduce the pod weight by moving the radar electronics into the GH fuselage while leaving the antennas and motion measurement units in the wing-mounted pods. However, we will need to develop smaller pods to reduce the diameter of the pods to create sufficient ground clearance (3") in the event of a landing gear failure. Redesigning new pods and updating the aerodynamic analysis will take at least one year and additional funding, which has not been identified. We are currently considering an interim implementation approach, where we remove the wing pods and mount only one radar antenna in the radome under the GH fuselage. This will allow us to conduct long duration flights with L-band polarimetry, but not single-pass interferometry. This implementation can be accomplished with significantly less funds and shorter time.

VI. P-BAND IMPLEMENTATION

The P-band addition to UAVSAR is well underway. We are currently designing a wide-band P-band antenna and 2 kW transmitter to operate UAVSAR in P-band for the AirMOSS project to measure subsurface and subcanopy soil moisture. One concern in the P-band implementation is the polarization contamination due to undesired multipath effect caused by antenna-wing interactions. We are conducting a detailed simulation to quantify this cross-polarization contamination and the effect on radar performance. Another concern is the potentially stringent absolute calibration accuracy requirement, which will require very stable radar electronics and internal calibration loop, and detailed characterization of the gain stability as a function of temperature and other factors. Additional mitigations include deploying accurate calibration targets at campaign sites and acquiring multiple data sets to reduce speckle noise. We are assessing these issues and expect to have mitigation strategies in time for the critical design review in late June.

VII. ADDITIONAL PLATFORM

Once the P-band radar receives spectrum permission to operate and is flight tested and calibrated, we expect to acquire about 350 hours' worth of soil moisture data per year for 3 years over 9 selected biome types in North America. The data acquisitions will occur between April and October, during the

vegetation growing seasons. The AirMOSS missions will add about 70 flights annually to the current UAVSAR L-band operations. NASA HQ has recently approved funding to modify a second G-III, currently based at Johnson Space Center, to support the AirMOSS missions. This will ease the potential conflicts between the L-band and AirMOSS missions, in addition to as yet unknown Ka-band missions once the Ka-band radar is flight tested and ready for operations. The JSC G-III modification will take about one year and should be ready by the time the P-band radar has completed its laboratory testing.

ACKNOWLEDGMENT

The work carried out in this paper was partially performed at Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration (NASA). The authors wish to thank NASA's Earth Science Technology Office for funding this technology development.

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